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The path from homogeneous to heterogeneous roughness drag models

Rune M. Jensen[1], Jiasheng Yang[2], Alexander Stroh[2], Bettina Frohnapfel[2], Shervin Bagheri[3] and Pourya Forooghi[1,*]

[1] Deptartment of Mechanical & Production Engineering, Aarhus University, 8200 Aarhus, Denmark

[2] Institute of Fluid Mechanics (ISTM), Karlsruhe Institute of Tech., 76131 Karlsruhe, Germany

[3]Division of Fluid Mechanics, KTH Mechanics, Royal Institute of Tech., 100 44 Stockholm, Sweden

* forooghi@mpe.au.dk

ABSTRACT

The question of how to determine the skin-friction drag on an 'arbitrary' rough surface merely based on the roughness topography has received a great deal of attention in the turbulent flow literature. Several correlations and models have been proposed ranging from empirical correlations to the recent data-driven models with multiple inputs (see Chung et al. (2021) for a comprehensive review).

While roughness in many real-world applications, including on ship hulls, is strictly heterogeneous, the vast majority of existing correlations and models are developed for homogeneous (and isotropic) roughness. This calls for an extension of the state of the art. The present contribution is an attempt to discuss the way ahead based on some recent results. Specifically we are interested to identify the most suitable set of inputs for both homogeneous and heterogeneous roughness models.

We begin with answering the question of what would be an ideal input into a model for homogeneous roughness. To this end, we introduce a recent data-driven model (Yang et al., 2023) trained based on a wide range of artificially generated irregular roughness samples characeterized using direct numerical simulation (DNS). The results show that a model with the discretized PDF and power spectrum of roughness height as inputs outperforms other forms of reduced order input in terms of generalizabiliy.

Subsequently, we will discuss the case of heterogeneous roughness - specifically patches of roughness on an otherwise smooth surface - using DNS data in plane channels. Here the roughness topography within the patches is simplified and the studied parameters are the patch shape, roughness coverage ratio, and heterogeneity length-scale Λ_P (defined as the square root of the total area divided by the number of patches). We show that, irrespective of the patch geometry, at roughly $\Lambda_P/\delta > 10$ the skin-friction coefficient virtually reaches an equilibrium value (δ is channel half height). Overall, the results suggest that the friction coefficient of heterogeneous roughness may be predicted by extending the existing homogeneous roughness models with a minimal number of added parameters including Λ_P/δ.

References

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